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U.S. DEPARTMENT OF COMMERCE
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ENVIRONMENTAL RESEARCH LABORATORIES

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Contracting Officer
Code 245
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Greenbelt, Maryland

Re: Type I Progress Report
Title: Remote Detection of Ocean Features in the
Lesser Antilles Using ERTS-1 Data
Task No. 432-641-14-05-10
Proposal No: 107
Principle Investigator: Dr. Kirby J. Hanson
GSFC ID: CO-005
Contract No: S-70246

Dear Sir:

At the end of October 1973, a special report on the progress, results and future plans of this project was presented to the Marine Resources Panel in Washington, D. C. To briefly summarize the report, our initial objectives were to investigate the possibility of remote detection of mechanically induced ocean eddies in the lee of the Lesser Antilles and to find the optimum spectral range for the detection of such eddies. Furthermore, if eddy formations were seen in the ERTS-1 imagery, we planned to study their time and space variability.

A close examination of the six ERTS-1 data sets which sampled the area near the Lesser Antilles between September 1972 and March 1973 has produced some unanticipated results. The ocean features seen in each of the six cases are most readily displayed and studied by spatial compositing of the negative prints made from the ERTS-1 positive transparencies. It has been determined that MSS band 5 (.6-.7 microns) has the optimum spectral range for viewing these surface features, offering a better contrast between photo density variations than the other bands. MSS 4 produces a much less distinct image, as expected, due to atmospheric attenuation.

The ERTS-1 data was studied in conjunction with ground truth oceanographic data which yielded inconclusive results. A comparison with surface winds and island topography, however, demonstrated that the ocean

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ABSTRACT

Photographic data received from the ERTS-1 satellite over the Lesser Antilles Islands shows distinct ocean features on the leeward side of each island. Attempts to relate these features to ocean eddy formations with the aid of ground truth data proved unsuccessful. However, analysis of surface and upper air wind data correlate extremely well with the size, shape, and downwind extent of the ocean features.

Studies to date indicate strongly that these features result from horizontal differences in sea surface roughness due to the wind shadow effect of the islands. The results suggest that horizontal variations in the reflectance of the sea surface will make remote sensing of the ocean mixed layer more difficult than previously anticipated. The surface reflection seems to be large enough to mask the smaller variations in backscattered energy from the mixed layer. Efforts to limit the effect of surface reflectance by photographic differencing of two MSS bands were unsuccessful. A supplementary study to enhance the energy reflected from the mixed layer through numerical differencing of ERTS-1 digital data is planned.

features seen in the ERTS-1 data result from horizontal differences in surface roughness due to the wind shadow effect of the islands. This suggests that surface reflectance (and its horizontal variation) will make remote sensing of the ocean mixed layer more difficult than previously thought.

Further investigations are under way to find a method to limit the effect of the variable surface reflectance by applying numerical differencing methods to the ERTS-1 digital data for 24 March 1973. It is hoped that a means will be formulated to alleviate the added problem involved in remote sensing of the mixed layer due to variations in sea state. Other work includes a computer enhancement of the 24 March ERTS-1 data with a technique developed by Mr. George Maul, NOAA, Physical Oceanography Laboratory, AOML. Also, we hope to receive several photographs of the Lesser Antilles region taken on consecutive days from SKYLAB III. This will allow us to complete a time study of the ocean features and to determine their variation with changes in wind speed and direction over several days.

An article on our research to date is included as a part of this Type I Progress Report. The paper is being submitted to the Journal of Physical Oceanography for possible publication.

Sincerely,



Kirby J. Hanson

Enclosure

cc: Mr. George Ensor, Technical Monitor
Dr. James R. Greaves, Scientific Monitor
Project Scientist, Code 650
ERTS Program Manager, Code ER

THE DETECTION BY ERTS-1 OF WIND INDUCED
OCEAN SURFACE FEATURES IN THE LEE OF
THE ANTILLES ISLANDS

by

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1. BACKGROUND

Investigations near Johnston Atoll by Barkley (1972) have shown that sufficient current flow produces a wake dominated by eddies on the leeward side of the island. Eddies with a cyclonic rotation bring deep water to the surface and, if the water is rich in nutrients, it could contribute significantly to the productivity of the area.

An example of this form of productivity enhancement was detected during a fishery oceanography survey of the eastern Caribbean near St. Vincent Island. Ingham and Mahnken (1966) found that tuna schools and bird flocks were concentrated in an area west of this Lesser Antilles island. They also noted that plankton and primary productivity in the mixed layer were higher in this area than the Atlantic, and that bathymetric data revealed the existence of horizontal temperature differences in the upper thermocline which might indicate the presence of eddy-like features in the ocean. They suggested the possibility that the increased productivity of this area is a consequence of downstream turbulence on the Caribbean side of St. Vincent Island.

Because of the capability of the ERTS-1 camera system to simultaneously view the same area through several different band pass filters, it was anticipated that ocean features similar to those mentioned above could be detected and monitored by the satellite. Although several ocean features were observed by ERTS-1 in the lee of the Lesser Antilles Island Arc, comparisons with ground truth data analyses by Hanson, et al. (1973) showed that the features were not associated with eddy-like formations.

2. ERTS-1 DATA ENHANCEMENT

ERTS-1, launched in July 1972, collected six MSS (Multispectral Scanner) data sets over the Lesser Antilles region from September 1972-April 1973, when a recording system failure caused the termination of data collection in that area. ERTS coverage in the four MSS bands were obtained for the following dates; 26 Sept., 13-14 Oct., 1 Nov., 19 Nov. 1972 and 17 Feb. and 24 Mar. 1973.

Each of these data sets indicate ocean surface features on the leeward side of many of the islands. They appear as areas of lower photo density in the ERTS-1 images. Five of the data sets are presented in Figures 2-6. The sixth MSS data set, collected on 1 Nov., is not included due to extensive cloudiness over the Antilles Arc; the only relatively clear area being west of Guadeloupe.

Several techniques to enhance the lower density range of the ERTS-1 positive transparencies have been studied. Density slicing of the ERTS-1 images through the use of a color densitometer was investigated. The densitometer allowed the assignment of up to thirty-two different colors to selected portions of the density range of the transparency, producing a false color image. Several attempts to enhance the lower photo density range did not improve the features seen in the ERTS-1 transparencies. Other tests with multispectral viewers, designed specifically to view transparencies produced from narrow band energies have indicated that near coastal or shallow water regions may readily be enhanced, but little success has been achieved in enhancing density differences across deep ocean features such as those in the lee of the Lesser Antilles.

The most effective photographic rendition of oceanic features is achieved by simple contact printing of the ERTS-1 positive transparencies, and arranging a spatial composite of the resulting negative prints. In this way the darker features in the lee of the islands show up as lighter areas which seem to bring out small changes in lower density. Figure 1 is a mosaic of negative prints for 13-14 Oct. in each of the four MSS bands:

ERTS Band	λ (microns)
MSS 4	.5-.6
MSS 5	.6-.7
MSS 6	.7-.8
MSS 7	.8-1.1

MSS 5 seems to have the optimum sensitivity for detecting these ocean features. The changes in photo density are much more clearly defined in MSS 5 than they are in MSS 4 and slightly clearer than MSS 6 and MSS 7.

3. ERTS-1 DATA INTERPRETATION

a. ERTS Photographic Data

Figure 2 shows the ERTS-1 coverage of the area west of Martinique. Although much of the region is covered with cirrus and small cumulus clouds, two lighter areas are visible near the top of the print. A narrow line extends to the southwest in the lee of the northern tip of Martinique. Another light feature can be seen at the top edge of the negative print to the northwest of Martinique which also extends in a southwest direction parallel

with the feature at the northern tip of the island. This feature appears to be originating from the western side of Dominica.

Figures 3 and 4 show the data received for the 13-14 Oct. and 19 Nov. orbits, respectively. In the October data, bright areas can be seen to the west of all the islands from Guadeloupe to Grenada and Tobago. The brightest area is to the west of St. Vincent. The features extend in a west to west northwest direction away from each island. On 19 November, only moderate indications of ocean features are evident. These features extend slightly south of west in the lee of Martinique, St. Lucia and Grenada. The longitudinal extent of the 19 November features is much smaller than in the other cases. One explanation for the diminished size of these ocean features is given in section 3b.

Figures 5 and 6 show the remaining photographic data collected near the Lesser Antilles Islands. On 17 February 1973, bright areas in the negative prints can be seen to the west of each island from Guadeloupe to St. Vincent even though several clouds are present. The features in this case extend slightly north of west as opposed to the component south of west noticed on 26 Sept. and 19 Nov. Similarly, on 24 March very bright features are seen on the leeward side of the island arc. These features have a component further north of west than that seen on 13-14 Oct. or 17 Feb.

b. Wind and Topography

The winds for each area displayed in Figures 2-6 were averaged to obtain a mean speed and direction for the region. The estimated direction

of each ocean feature was also determined by measuring the angle between a meridian and a line drawn through the center of each feature. An average angle was calculated for each day. The resulting correlation between the wind and the direction of the ocean features is given in Table 1.

It can be readily seen from the table that the directions of the wind and ocean features are in agreement within a few degrees. Clearly, the winds and the ocean features detected by the ERTS-1 satellite are directly related.

It is also suggested in Table 1 that wind speeds between ten and fifteen knots produce very well defined features on the leeward side of the islands while speeds near twenty knots greatly diminish the size and sharpness of the features as shown, for example, by the 19 November features. The apparent inverse relationship between wind speed and feature size and clarity is most likely caused by the topography of each island, i.e., it appears that the height and orientation of the islands block the air flow most effectively when wind speeds are below 15 knots.

The Lesser Antilles are volcanic islands and therefore very mountainous with only a few low, relatively flat areas. Guadeloupe, Dominica, St. Lucia, St. Vincent, and Grenada have mountain ranges extending north-south with heights above three or four thousand feet on most islands. When the wind is nearly perpendicular to the mountain ranges, the ocean features have almost the same width as the islands. However, when the wind direction is at an acute angle to the north-south mountain ranges, as in the 26 September case, the ocean features become more narrow.

Furthermore, Martinique, which has mountains at its northern end over 4000 feet and relatively low lands under 1500 feet at the southern end, causes the ocean feature to be only as wide as the northern half of the island, even when the wind is perpendicular to the mountains.

Further evidence that the influence of topography on the air flow is the main cause of these ocean features can be seen by studying the area in the ERTS-1 prints to the west of Barbados. Barbados is a relatively flat island; its highest peak being just over 1100 feet. The ERTS-1 orbits of 13 October and 24 March pass sufficiently close to Barbados so that any ocean feature extending from that island would be seen on the eastern edge of the ERTS-1 image. However, there is no feature visible in either ERTS-1 print, suggesting that the topography of Barbados is too low to produce an extensive wind induced feature on its leeward side.

c. Surface Reflectance

It is apparent from the ERTS-1 data that changes in wind speed greatly effect the amount of backscattered energy due to the variation in surface roughness. As a result, it appears that remote sensing of the mixed layer will be more difficult than previously anticipated because the energy reflected from the ocean surface must be taken into account. Since the ERTS-1 multispectral scanner senses the same area in four separate energy bands at the same time, it may be possible to minimize in the data the effect of energy reflected from the surface by taking energy differences between two spectral bands. Thus, the difference between bands 4 and 7, for example, would be more representative of the energy reflected from below the ocean surface.

By superimposing two ERTS-1 transparencies, one being a positive and the other a negative, the energy reflected from the surface would be minimized and the resulting image would tend to enhance the radiation back-scattered from the subsurface. This photographic differencing technique was employed in an attempt to detect changes in the photo density patterns, indicative of subsurface eddy formations. Unfortunately, there was no noticeable change in the variations of photo density after applying this method to the 13-14 Oct. data.

A study is presently underway to limit the effect of surface reflectance by taking numerical differences of the ERTS-1 digital data near St. Vincent on 24 March 1973. Hopefully, some positive results will be obtained to help alleviate the difficulties of remote sensing of the mixed layer due to large horizontal variations in sea surface roughness.

4. CONCLUSIONS

The results of studies with ERTS-1 photographic data of the Lesser Antilles Island Arc have shown that changes in sea state have a large effect on the amount of backscattered solar radiation reaching a satellite sensor. Smoother seas cause a decrease in the energy reflected from the ocean surface. This is immediately apparent from the negative ERTS-1 prints (Fig. 1-6) which display much lower photo densities in the wind shadow of each island than in the open ocean, unprotected from the wind. It is evident from this study that horizontal variations in the reflectance of the sea surface will make remote sensing of the ocean mixed layer more difficult.

Preliminary attempts to remove the surface reflectance by photographic differences have not yielded positive results. Future studies will concentrate on numerical differencing between ERTS-1 spectral images. The findings may produce a method to minimize the effect of surface reflectance and qualitatively describe horizontal variations in particles in the ocean mixed layer through remote sensing.

Acknowledgment

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FIGURES

1. 13-14 Oct. 1972 ERTS Coverage - MSS Bands 4-7
2. 26 Sept. 1972 ERTS Coverage - MSS Band 5
3. 13-14 Oct. 1972 ERTS Coverage - MSS Band 5
4. 19 Nov. 1972 ERTS Coverage - MSS Band 5
5. 17 Feb. 1973 ERTS Coverage - MSS Band 5
6. 24 Mar. 1973 ERTS Coverage - MSS Band 3

TABLE

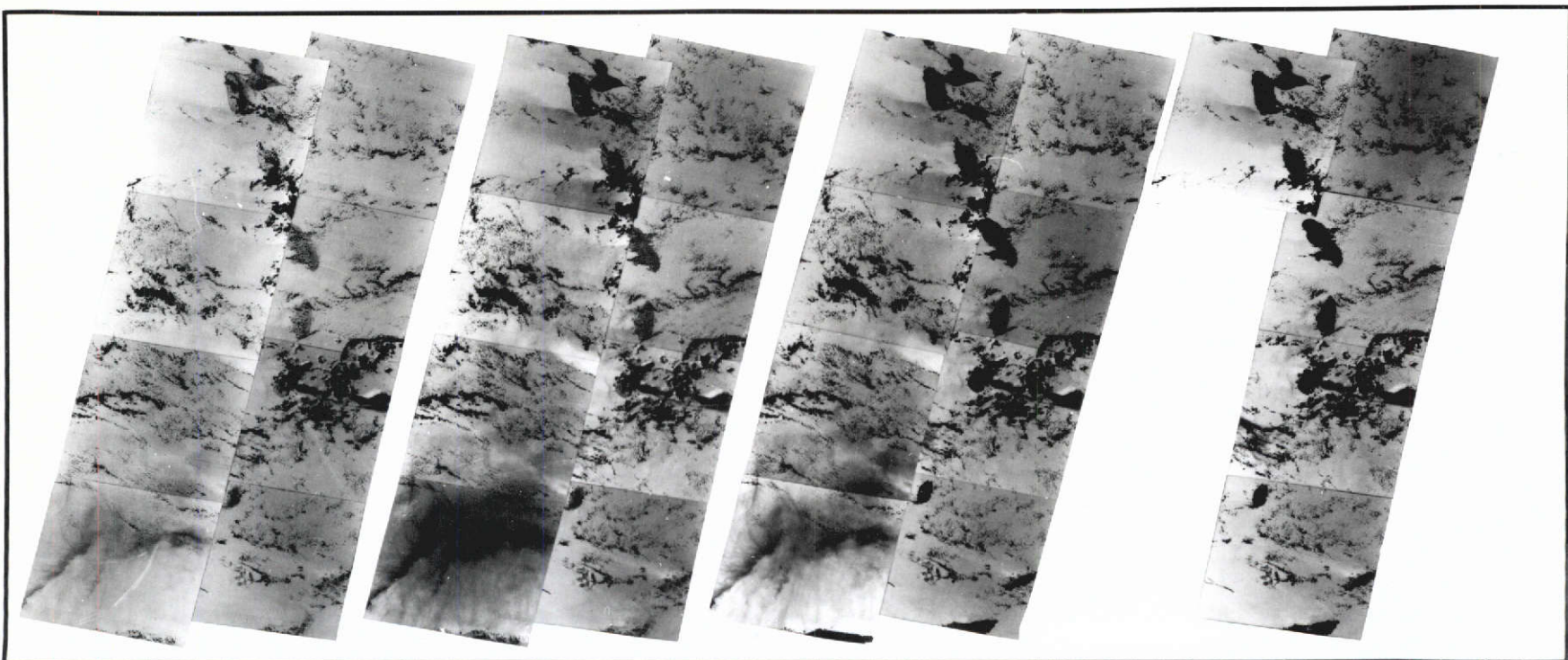
1. Observed wind speeds and directions and estimated direction of ocean surface features in the lee of the Antilles Islands.

TABLE 1

Average	26 Sept.	13 Oct.	14 Oct.	19 Nov.	17 Feb.	24 Mar.*
Wind Speed	10	10	13	19	12	10
Wind Direction	60°	110°	103°	85°	99°	116°
Estimated Direction of Ocean Features	57°	105°	101°	83°	102°	114°

*The mean wind for 24 March does not include the two ship reports southwest of Barbados which are due to local weather conditions.

14



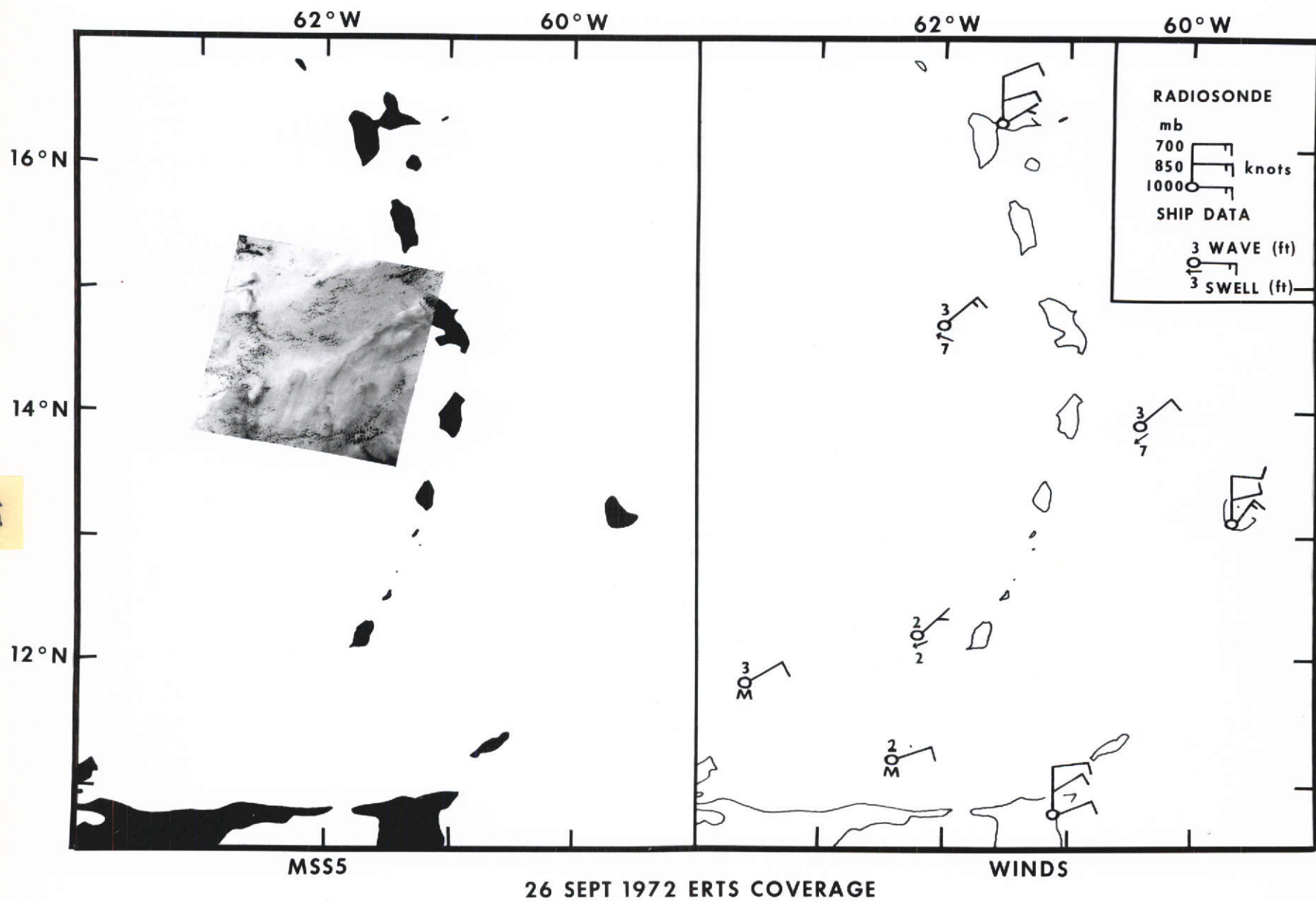
MSS 4

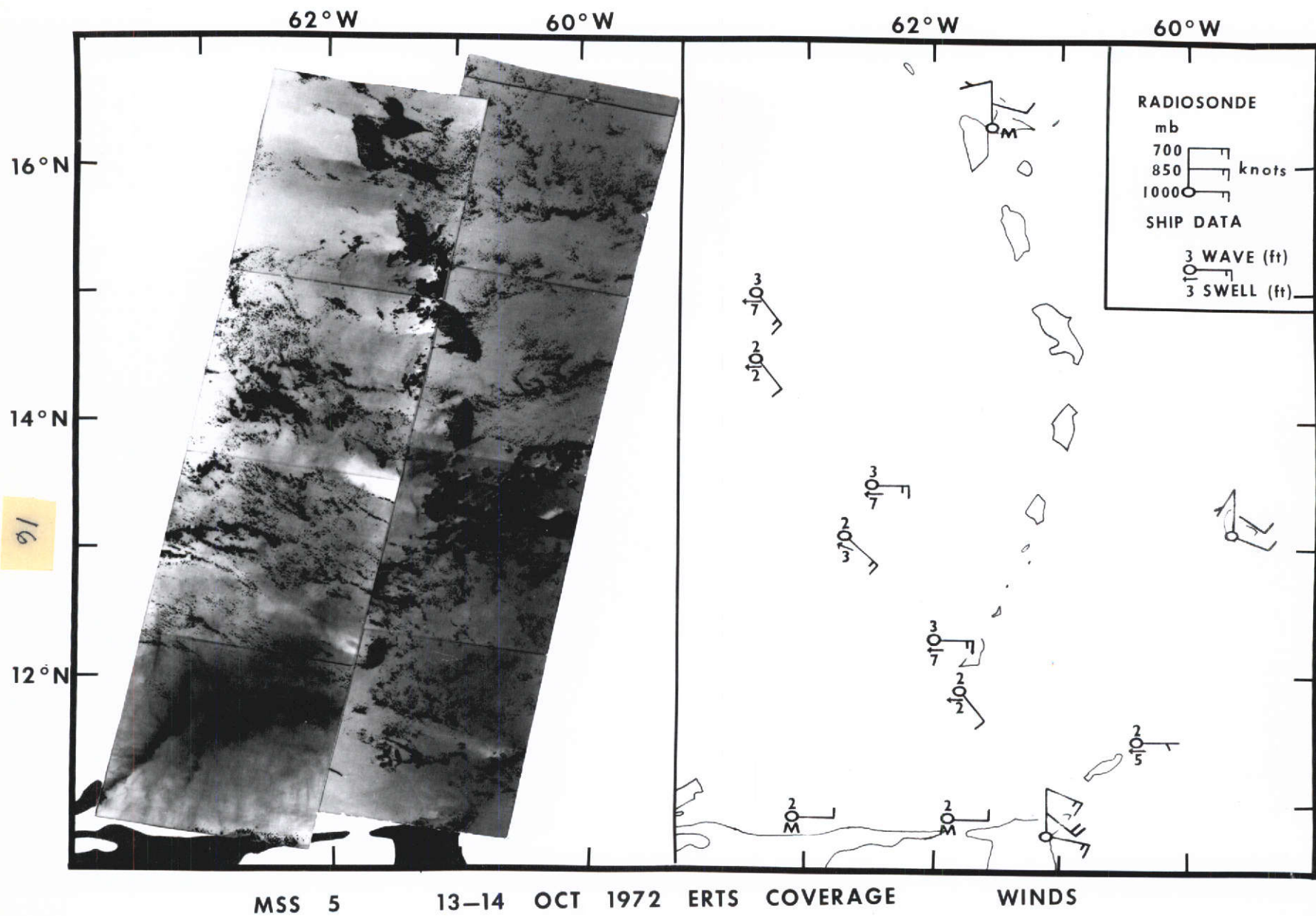
MSS 5

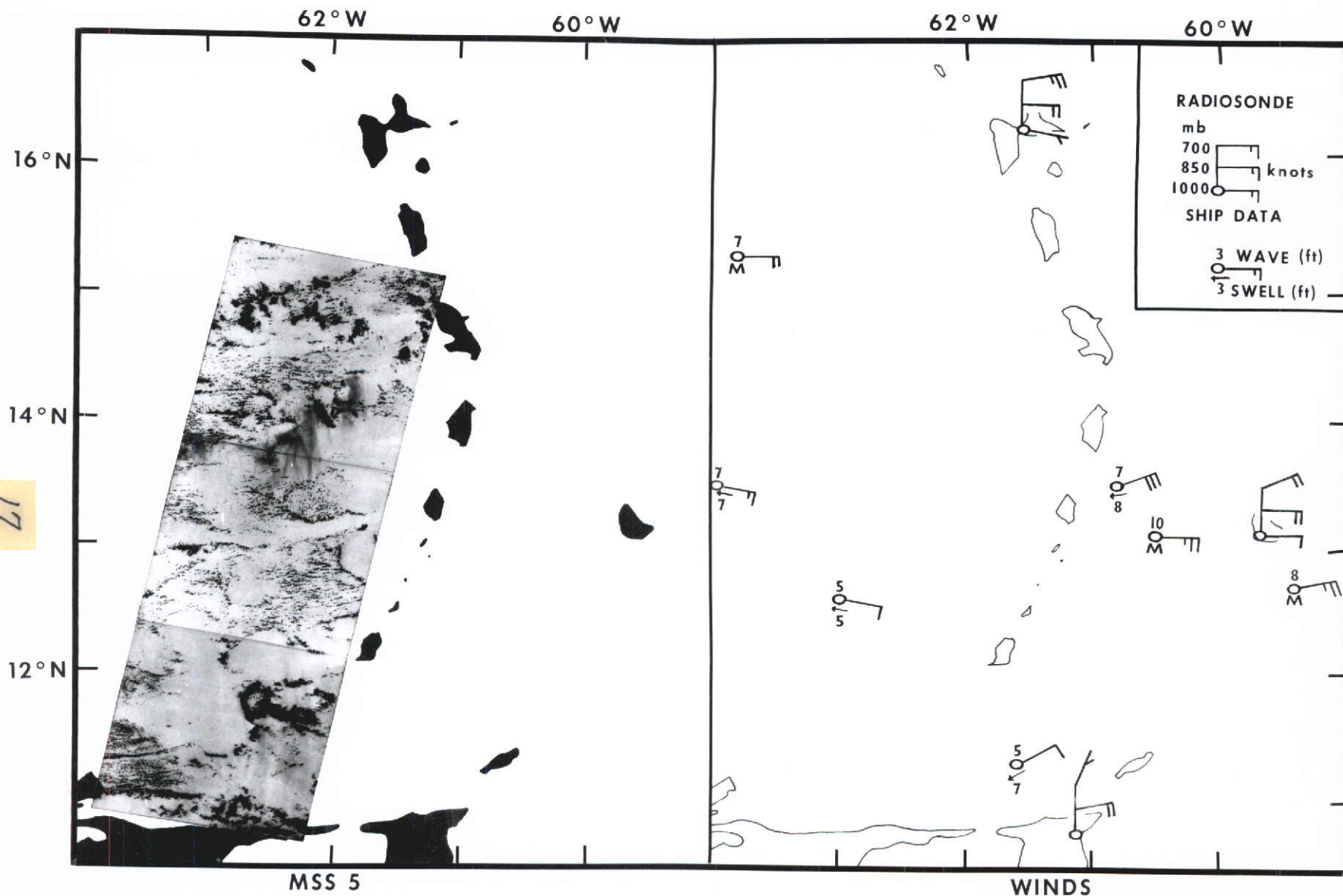
MSS 6

MSS 7

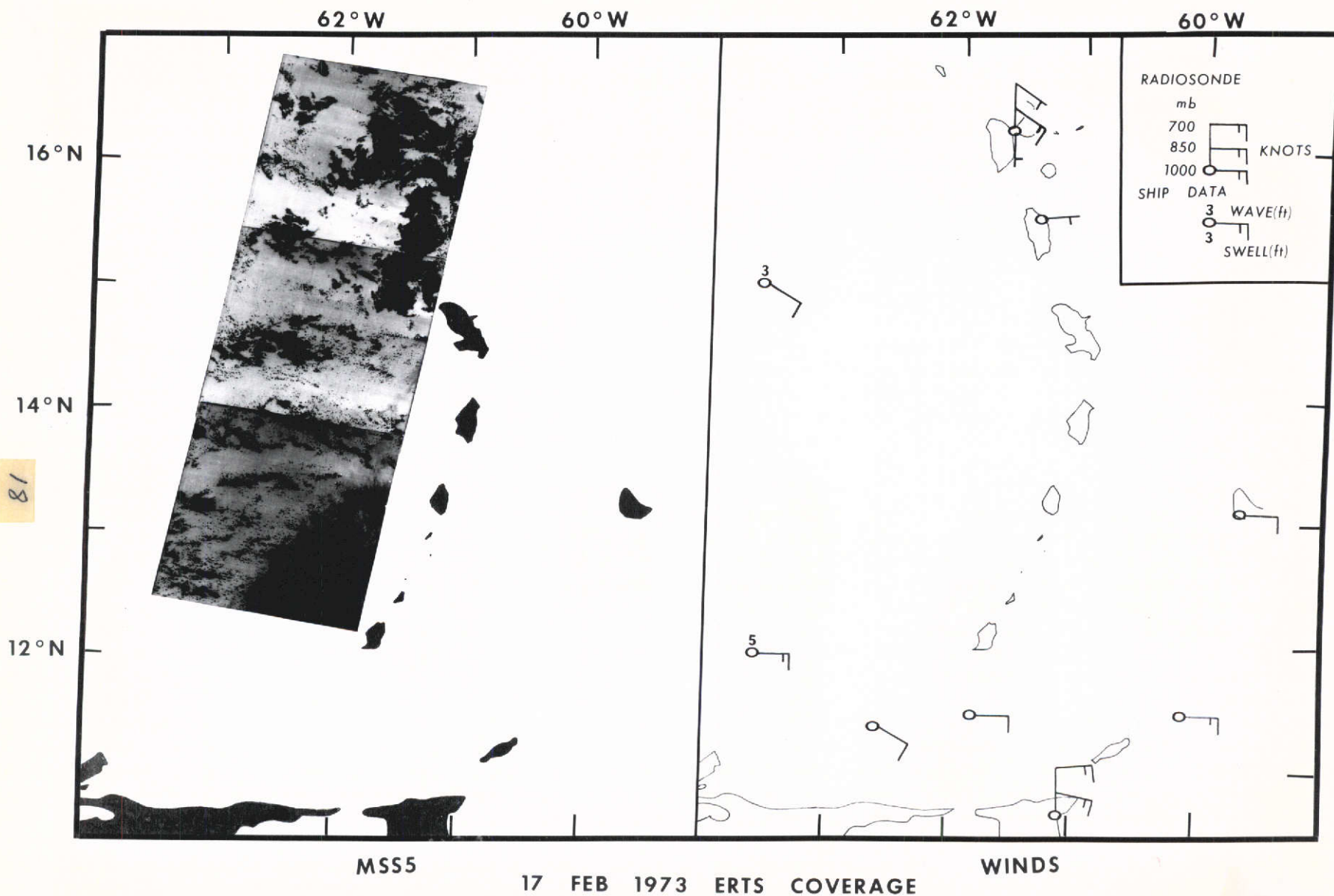
ERTS COVERAGE OF THE LESSER ANTILLES
13-14 OCT 1972

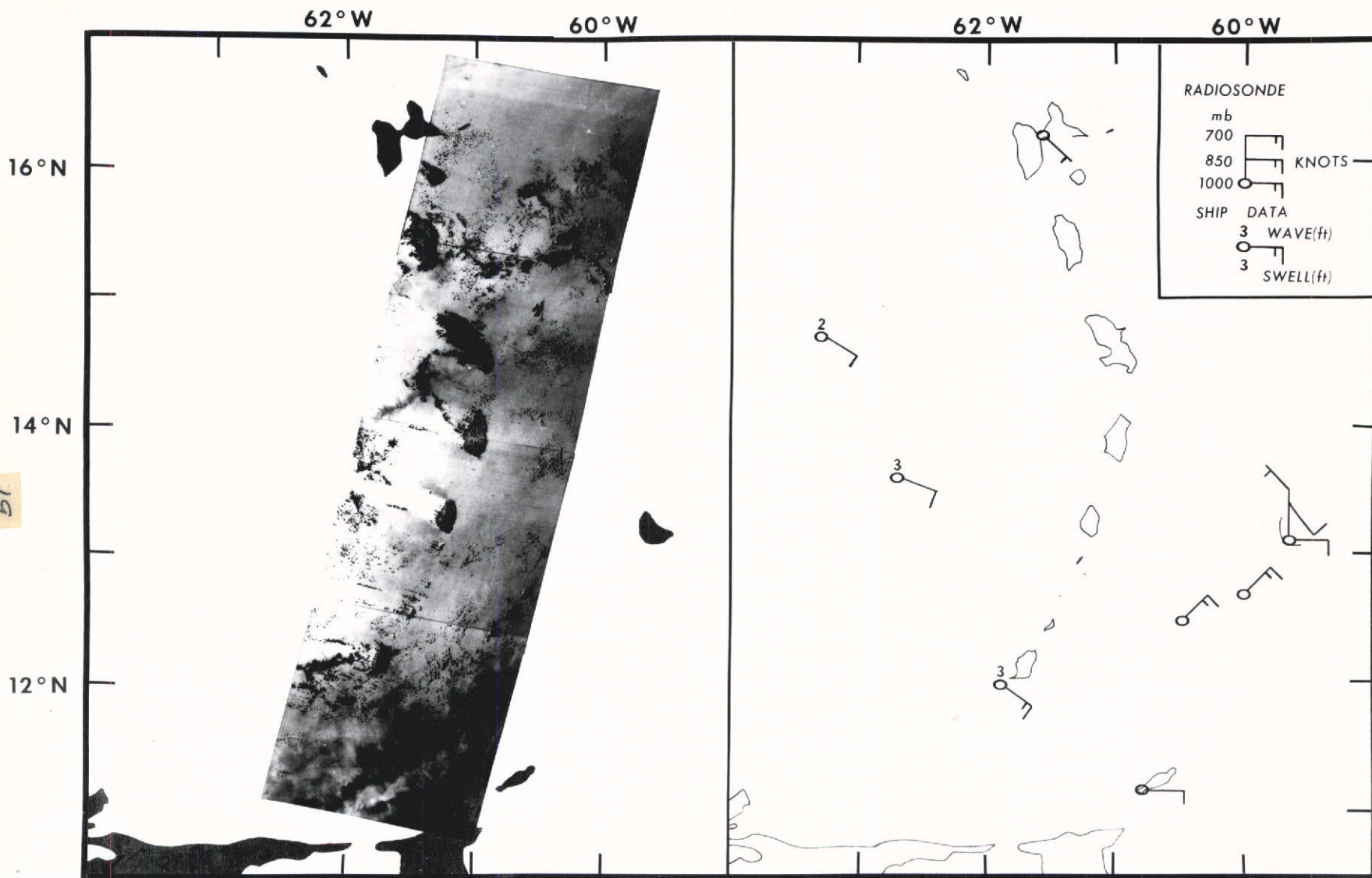






19 NOV 1972 ERTS COVERAGE





MSS5

24 MAR 1973 ERTS COVERAGE

WINDS